“Composite Gas Sensors: Synthesis, Physical Properties and Device Design”

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1. Basics of Gas Sensors with Historical Details

Sensor gives the idea to come from the word ‘sense’ given generally that the sensor devices try to reproduce human senses characteristics. The reason for the output of a sensor to be limited to electrical signals is related to the present improvement of a signal processing, that is almost completely performed using electronic instruments. From the definition, a sensor is a gadget that receives physical, biological, chemical signals and transfers them into an electrical signal which should be companionable with electronic circuits and instrument. Typical human nose has 400 types of scent receptors enabling us to smell about 1 trillion different colors. But still many of us do not have the capacity to identify the type or concentration of a gas present in our atmosphere. This is where sensors come in. There are several types of sensors to measure different parameters and a gas sensor is one which comes handy in applications where we have to detect the variation in the concentration of toxic gases in order to maintain the system safe and avoid/caution any unexpected fears. There are various gas sensors to detect gases like oxygen, carbon dioxide, nitrogen, methane etc. They can also be commonly found in devices that are used to detect the leakage of the harmful gases, monitor the air quality in industries and offices etc. A gas sensor is a device which detects the presence or concentration of gases in the atmosphere.

Based on the concentration of the gas the sensor produces a corresponding potential difference by changing the resistance of the material inside the sensor, which can be measured as output voltage, types of sensors are; metal oxide-based gas sensors, optical gas sensors, electrochemical gas sensors, capacitance based sensors, and calorimetric gas sensors etc. The ability of a gas sensor to detect gases depends on the chemi-resister to conduct current. The sensor system consists of three major components; a) sensor unit, is part where the actual sensor material interact with the analyte e.g. Bi_2O_3 nanorods on glass substrate, b) signal processor, a component receives the electrical output of the sensors and transforms into a more suitable form c) amplifier, converting to digital form and output transducer is termed for converting again the electrical single into a non-electrical parameters.

A gas sensor informs one or more physical properties of any material at ambient temperature when upon interaction with chemical species (adsorption, charge transfer and chemical reaction). The physiochemical properties of metal oxide sensitive layer include operation temperature, mass, and electrical resistance [3]. These changes are converted into electrical signals such as

current, frequency, impedance/conductance or voltage, which is then read out subjected to further data treatment and processing. This type of tool is used for the detection of gas leakage or other emissions and can be controlled by an alarm because there are many gases that can be flammable harmful, toxic to organic life, such as humans or animals scientists and engineers around are actively engaged in fulfilling above requirements by making sensors of various nanostructures, polymers, and their composite/hybrid counterparts [4]. Metal oxide nanostructures can be synthesized by chemical, biological and physical methods. In comparison to other, chemical method (solution process) is easy, economical, operating at optimum conditions (low temperature and pressure) and therefore commonly used for the synthesis of Metal oxide semiconductors (MOSs), represent a class of unique materials due to their electronic charge transport properties.

Semiconducting metal oxides such zinc oxide, bismuth oxide, tin oxide, iron oxide, and titanium oxide are being studied to develop cost-effective gas sensors to various gases specifically [1]. The bismuth oxide, is one of the important metal oxides, is of low cost, relatively abundant and environmental friendly (band gap decreases due to annealing effect) [2]. The nano-stuctured metal oxide based sensors have rarely demonstrated room-temperature sensor performance due to their semiconducting character. Thereby, these insulating and high energy band gap metal oxide sensors like TiO_2 [5], Co_3O_4 [6], ZnO [7], In_2O_3 [8] and SnO_2 [9] etc., are unable to produce considerable sensitivity at room or moderate operating temperatures. On doping or monitoring oxygen vacancies, they can be operated at reasonably low temperature ($<=100^0$ C).

Literature review

- Patil *et al.* prepared nanostructured ZnO thin film based gas sensor by using the simplistic and economical successive ion layer adsorption and reaction (SILAR) technique. The effects of SILAR cycles on the structural, optical, surface morphological and electrical properties of nanostructured ZnO thin films were investigated The SILAR cycles play a key role in the synthesis of nanostructured ZnO thin films and it is found that, with increasing SILAR cycles, the grain size continues increasing. [7].
- Yan *et al.* synthesized flower-like α-FeOOH precursors by using $FeSO_4 \cdot 7H_2O$ and $CO(NH_2)_2$ as raw materials at 80 °C for 6 h without any template and surfactant. As a demonstration of potential application for gas-sensing materials, the porous flower-like

superstructures exhibited short response/recovery time within 6/3 s, and presented a much higher gas response than α-Fe_2O_3 nanoparticles aggregations towards different concentrations of ethanol, methanol and acetone [10].

- Supriya *et al.* demonstrated an extremely simple but very effective solid– state synthesis method for the fabrication of various metal oxide nanostructures. DSSC (dye synthesized solar cell) with low temperature treated ZnO photoanode obtained using the solid-state reaction has demonstrated a power conversion efficiency of 5% [11].
- Bandgar *et al.* developed novel low-temperature flexible polyaniline ammonia (PAni) gas sensor. The developed laboratory scale flexible PAni sensor demonstrated industrial potential for use in dangerous locations dealing with hazardous gases, due to its easy synthesis methodology, low cost, low operation temperature, and flexibility etc., where high temperature operations are, in general, restricted [12].

2. Methodology and Characterizations

The working principal of gas sensor is based on a change in electrical conductivity due to surface reactions such as oxidation or reduction caused by an exposure to various gases. These sensors will be prepared using a **Doctor Blade Method** as shown in below Figure(1).

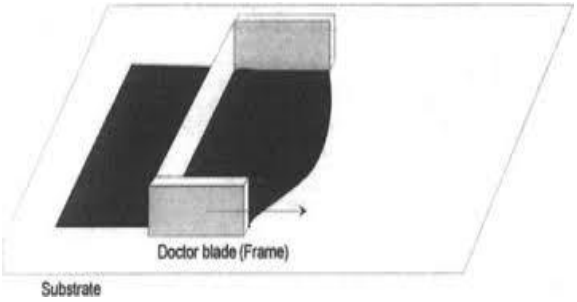

Fig 1. Doctor Blade Method.

In this process a thick slurry paste, containing an organic solvent such as ethanol and various other additives (e.g., polymer binder), is bladed onto a substrate in order to get metal oxide films by solid state reaction.

After synthesis, film sensors will be characterized with different characterization techniques like X-ray diffraction (XRD), field-emission scanning electron microscopy (FE-SEM) and Raman

shift analysis etc. The structural elucidation and crystallinity of sensors will be studied by XRD pattern, also analyses the single phase formation of metal oxides. Morphology, particle size and shape are revealed through FE-SEM. Raman spectroscopy is used to observe vibrational, rotational , and low frequency modes in a system. Composite gas sensors will be designed after studying these physical properties. Surface analysis will also be carried out for knowing the surface elements.

3. Scientific temperament

The developments in gas sensor technology must be economic, eco-friendly, chemically stable, and environmentally robust; furthermore sensor materials should not add to the environmental risk. The detection of inflammable and explosive gases has become an important area of research. The leakage of such gases can cause major explosions /accidents. The LPG, one of the highly inflammable and potentially hazardous gas is widely used in household, vehicle fuels, and at the industry level. However, metal oxide based gas sensors have several limitations such as expensive metal salts, toxicity, high operating temperature and chemical instability. It is widely accepted that gas sensors based on metal oxide nanostructures have limited surface area, require elevated temperatures for their efficient operation; a pressing goal is to reduce the operating temperature without any loss of gas sensitivity.

Zinc oxide (ZnO) thin films have been widely used as an effective gas sensor element. In the present study, nanostructured thin films of ZnO were prepared by using the simplistic and economical SILAR technique. The effects of SILAR cycles on the structural, optical, surface morphological and electrical properties of nanostructured ZnO thin films were investigated. ZnO, due to high energy band gap, is unable to produce considerable sensitivity at room temperature [7]. And based on LPG sensing results, it was concluded that the SILAR synthesized NiO films was probable candidate for detecting LPG at lower concentration and lower temperature, hence, **our motive is to get gas sensor with high sensitivity, and with low/room temperature detection by composites of any two metal oxides' thin films in order to get a sensor, named composite gas sensor.**

4. Objectives

- Fabrication of individual and composite sensors of different metal oxides like Bi_2O_3, ZnO, Sb_2O_3, SnO_2, and Fe_2O_3 using solid state chemical route followed doctor blade method.
- To anneal these sensors at ambient temperature for improving the surface stickiness
- To measure physical characteristics for knowing structure, surface morphology, surface elements and phase etc.
- To expose individual and composite sensors for various gases like LPG, ethanol, methanol, carbon dioxide, nitrogen dioxide etc., for knowing gas selectivity
- To find out the effect of gas concentration on sensitivity and repose time/recovery time of the as-developed sensors
- To check chemical stability and mechanical robustness of the composite sensor using durability test
- To corroborate results computational analysis using density function theory, if required
- To write and publish manuscripts in high indexed journals.

5. References

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